

CHONDROCYTE THERAPEUTIC DELIVERY SYSTEM

FIELD OF THE INVENTION

[0001] This invention relates to the treatment or amelioration of disorders or diseases using chondrocytes to deliver therapeutic agents.

BACKGROUND OF THE INVENTION

[0002] Chondrocytes are typically involved in cartilage repair. Cartilage is a structural support tissue that is found in the body in three main varieties. Hyaline, or articular cartilage, helps dissipate loads in joints. In articular cartilage, chondrocytes are encapsulated in a woven, mesh-like matrix of type II collagen and proteoglycans. Elastic cartilage provides flexible support to external structures, and is composed of chondrocytes embedded in a matrix of collagen and elastic fibers. Fibrocartilage aids in transferring loads between tendons and bone. It consists of an outer layer of collagen and fibroblasts that support and inner layer of chondrocytes that make type II collagen fibers.

[0003] To date chondrocytes have been used to correct or repair cartilaginous defects. For example, by placing chondrocytes into hydrogels and injecting the chondrocytes into a cartilage defective region. The chondrocytes are used to express matrix proteins required for cartilage repair. Although chondrocytes have been cultured and placed into substrates such as hydrogels, for treatment, or repair of cartilage or bone defects, there is no teaching in the art that chondrocytes can be used to express therapeutic agents for the treatment of pathologies or injuries other than cartilage tissue.

[0004] Accordingly, a need exists for using chondrocytes to deliver therapeutic agents to tissue or organs within the body, and particularly to an environment that is not usually associated with chondrocytes. A need also exists for using an implant comprising genetically altered chondrocytes that can locally express and release therapeutic agents

into a target region or environment. A further need exists for using chondrocytes as a large scale manufacturing source for therapeutic agents.

SUMMARY OF THE INVENTION

[0005] The present invention provides methods and compositions for using genetically altered chondrocytes as vehicles to express therapeutic agents. The methods of the invention are particularly conducive to the use of chondrocytes for expressing a therapeutic agent in localized environments that are not typically associated with chondrocytes. Specifically, the genetically altered chondrocytes can be used to express therapeutic agents, such as proteins or antibodies, into localized environments such as the central nervous system (e.g., the brain or spinal cord) or into solid organs (e.g., heart, liver or kidney). This type of localized delivery and expression of the therapeutic agent provides a localized concentration of the therapeutic agent in a particular region, without the necessary side effects that result from systemic administration of the therapeutic agent. The genetically altered chondrocytes can be introduced into these environments, using suitable matrix substrates, such as biological gels (e.g., hydrogels).

[0006] Chondrocytes offer several unique advantages as vehicles for expressing therapeutic agents over other cell types. For example, chondrocytes do not require vascular support, therefore can readily be used in environments that have a reduced, or non-existent vascularization system. Furthermore, chondrocytes are able to survive in harsh *in vivo* environments, including ischemic tissue, as well as low pH and low oxygen surroundings. In addition, there is a reduced likelihood of malignancy due to the anti-angiogenicity properties of normal chondrocytes. Chondrocytes also possess an immune privileged property which reduces immune rejection of co-implanted allogenic or xenogenic tissue. Furthermore, chondrocytes are more easily scalable compared to other normal untransformed cell strains.

[0007] The genetically altered chondrocyte can be used to deliver and express therapeutic agents in an environment that requires modification with the therapeutic agent. In one

embodiment, the genetically altered chondrocytes can be used to express a therapeutic agent in an environment associated with chondrocytes, such as the cartilage, tendons, joints, and bones. When the genetically engineered chondrocytes are used to express therapeutic agents in environments associated with chondrocytes, they are used for the purpose expressing the therapeutic agent, they do not become part of the structural component of the environment, i.e., they are not used as a component of a tissue engineered construct to repair or replace a damaged cartilage, tendon, joint, or bone. In another embodiment, the genetically altered chondrocytes are used to produce a therapeutic agent at an ectopic site, that is, in an environment that is not typically associated with chondrocytes such as the brain, or solid organs (e.g., heart, kidney, liver). Other atypical chondrocyte environments include an aqueous environment such as blood, and plasma.

[0008] The genetically altered chondrocyte can be mixed with a biocompatible substrate, such as a gel matrix substrate or another scaffold matrix made of natural or synthetic material. This genetically altered chondrocyte-gel matrix substrate or chondrocyte-scaffold matrix can be injected to a target region. Alternatively, the genetically altered chondrocyte-gel matrix substrate or chondrocyte-scaffold matrix can be prepared prior to implantation to a target region and surgically implanted into an ectopic site. The genetically altered chondrocytes can be used to treat or ameliorate a number of disorders by modifying the cell associated with the disorder by expressing the therapeutic agent. The cells associated with a disorder include disorders such as a blood disorder; a cardiovascular disorder; an endocrine disorder; an autoimmune disorder; a neurological disorder; a skin disorder; bone disorder (osteoporosis); a fertility disorder; a metabolic disorder or uncontrolled growth disorder such as cancer. In other embodiments, the genetically altered chondrocytes can also be used to address conditions that are not associated with a disorder, for example, to express a therapeutic agent such as hormones for birth control and reproduction.

[0009] Accordingly, in one aspect, the invention pertains to a genetically altered chondrocyte used for expressing a therapeutic agent. The genetically altered chondrocyte

is delivered to a cell associated with a disorder and expresses the therapeutic agent to modify an environment surrounding the cell. However, the genetically altered chondrocyte is not structurally functional the environment surrounding the cell.

[0010] In one embodiment, the cell associated with a disorder can be a cell in an atypical chondrocyte environment such as an organ selected from the group consisting of the brain, heart, liver, kidney, gastro-intestinal tract, spleen, smooth muscles, skeletal muscles, eye, ganglions, lungs, gonads, and pancreas. With organs, the genetically altered chondrocyte can be delivered to one or more regions of the organ. The atypical chondrocyte environment can also be an aqueous environment selected from the group consisting of blood, plasma, the vitreous humor of the eye, spinal fluid, and the like. The genetically altered chondrocyte can be delivered to the spleen, the bone marrow, a ganglion, the peritoneal cavity or any other well vascularized tissue for release into the blood or plasma. In another embodiment, the cell associated with a disorder is in a typical chondrocyte environment such as a bone, tendon and cartilage.

[0011] The genetically altered chondrocyte can be delivered on their own or in a mixture with a biocompatible substrate. The biocompatible, bioabsorbable substrate can be a substantially solid polymeric material or it can be in the form of a gel matrix. In a preferred embodiment, the biocompatible substrate is gel matrix substrate.

[0012] The cell associated with a disorder can be a cell selected from the group consisting of a cell associated with a blood disorder, a cell associated with a cardiovascular disorder, a cell associated with an endocrine disorder, a cell associated with an autoimmune disorder, a cell associated with a neurological disorder, a cell associated with a skin disorder, a cell associated with fertility disorder, and cell associated with reproduction.

[0013] The genetically altered chondrocyte can also be used to express a therapeutic agent in a target region associated with a disorder by delivering (e.g., ectopically) the genetically altered chondrocyte to at least one target region. The therapeutic agent that is expressed in the target region can either modify the target region alone (e.g., localized

targeting of a target region, e.g., a knee joint). Alternatively, the genetically altered chondrocytes can be used to express a therapeutic agent in the target region, but the therapeutic agent can modify the environment surrounding the target region (e.g., using chondrocytes to express insulin in the pancreas, where the expressed insulin effects the systemic blood glucose concentration).

[0014] Accordingly, in another aspect, the invention pertains to a genetically altered chondrocyte used for expressing a therapeutic agent in a target region associated with a disorder, wherein the genetically altered chondrocyte is delivered to the target region and expresses the therapeutic agent to modify the target region or an environment surrounding the target region, and wherein the genetically altered chondrocyte is not structurally functional in the target region or the environment surrounding the target region.

[0015] In yet another aspect, the invention pertains to a method for modifying an environment of a cell associated with a disorder using a genetically altered chondrocyte, by delivering a genetically altered chondrocyte to the cell associated with the disorder, wherein the genetically altered chondrocyte has been altered to express a therapeutic agent, and wherein the genetically altered chondrocyte is not structurally functional in the environment surrounding the cell. The therapeutic agent is then expressed at a level sufficient to modify the environment surrounding the cell. The environment can be one associated with a chondrocyte under the provision that the genetically altered chondrocyte is used only to express the therapeutic agent. The genetically altered chondrocyte is not structurally functional within the structure of the environment. In a preferred embodiment, the environment is chondrocyte atypical environment, such as the brain, heart, liver, kidney, pancreas, skeletal muscle, skin, spinal cord, spleen, eye, peritoneal cavity, gastro-intestinal track, or regions thereof.

[0016] In yet another embodiment, the invention pertains to a method for ameliorating a disorder in a subject using a genetically altered chondrocyte, by implanting a biocompatible substrate comprising a genetically altered chondrocyte into a target region of the subject, wherein the genetically altered chondrocyte has been altered to produce a

therapeutic agent, and wherein the genetically altered chondrocyte is not structurally functional in the target region or an environment surrounding the target region. The therapeutic agent is then expressed in the target region at a level sufficient to ameliorate the disorder.

[0017] The biocompatible substrate that is implanted can be a gel matrix substrate, such as an alginate, polysaccharide, and agarose. This genetically altered chondrocyte-gel matrix substrate can be injected to a target region. Alternatively, the genetically altered chondrocyte-gel matrix substrate can be solidified prior to implantation to a target region. When the chondrocyte-gel matrix substrate can be solidified prior to implantation, the dimensions of the implanted gel matrix substrate determine the concentration of chondrocytes within the gel matrix substrate that are available to express the therapeutic agent. The concentration of chondrocytes in the gel matrix substrate is in the range of about 10,000 to hundreds of millions of cells per ml of gel matrix having a volume in the range of about 0.1 to 10 ml. Preferably, the concentration of the chondrocytes is about 100,000 to about one million cells per ml of substrate. Preferably, the volume of the gel matrix substrate is less than one milliliter. It is understood that the dose necessary to treat a particular pathology could be easily optimized by either changing the cellular concentration for a given allowable volume, or by changing the amount of chondrocyte-gel implanted. The injury to be ameliorated can be a wound, a bone defect, a cartilage defect, a skin wound, and a torn ligament. The disorder that can be ameliorated can be a blood disorder, an autoimmune disorder, a hormonal disorder, an anti-inflammatory disorder, a fertility disorder, and an neurodegenerative disorder.

BRIEF DESCRIPTION OF DRAWINGS

- [0018] FIG. 1 is a photograph of cultured bovine chondrocytes;
- [0019] FIG. 2A is a phase contrast photograph of chondrocytes transfected with Green Fluorescent Protein (GFP);
- [0020] FIG. 2B is a chondrocyte from FIG. 2A showing expression of Green Fluorescent Protein (GFP);
- [0021] FIG. 3A is a graph showing expression of EPO from human chondrocytes;
- [0022] FIG. 3B is a graph showing expression of EPO from bovine chondrocytes;
- [0023] FIG. 4 is a graph showing expression of EPO mimetibody from human chondrocytes;

DETAILED DESCRIPTION OF THE INVENTION

- [0024] The practice of the present invention employs, unless otherwise indicated, conventional methods of virology, microbiology, molecular biology and recombinant DNA techniques within the skill of the art. Such techniques are explained fully in the literature. (*See, e.g.,* Sambrook, *et al.* Molecular Cloning: A Laboratory Manual (Current Edition); DNA Cloning: A Practical Approach, Vol. I & II (D. Glover, ed.); Oligonucleotide Synthesis (*N. Gait, ed.,* Current Edition); Nucleic Acid Hybridization (*B. Hames & S. Higgins, eds.,* Current Edition); Transcription and Translation (*B. Hames & S. Higgins, eds.,* Current Edition); CRC Handbook of Parvoviruses, Vol. I & II (*P. Tijessen, ed.*); Fundamental Virology, 2nd Edition, Vol. I & II (*B. N. Fields and D. M. Knipe, eds.*)).
- [0025] So that the invention may more readily be understood, certain terms are first defined:
- [0026] The term "chondrocyte" as used herein refers to the art recognized use of the term for a cell type involved in cartilage formation and repair. The chondrocyte functions to produce extracellular matrix of proteoglycans and collagen. Also included

with in the use of the term “chondrocyte” are chondrocyte precursor cells such as chondroblasts, and mesenchymal stem cells.

[0027] The term “genetically altered chondrocyte” as used herein refers to a chondrocyte cell that has been manipulated using standard molecular biological techniques, in a way that introduces a heterologous or foreign nucleic acid molecule encoding a therapeutic agent into the cell.

[0028] The term “nucleic acid” sequence as used herein refers to a DNA or RNA sequence. The term captures sequences that include any of the known base analogues of DNA and RNA such as, but not limited to, 4-acetylcytosine, 8-hydroxy-N6-methyladenosine, aziridinylcytosine, pseudoisocytosine, 5- (carboxyhydroxymethyl) uracil, 5-fluorouracil, 5-bromouracil, 5-carboxymethylaminomethyl-2-thiouracil, 5-carboxymethylaminomethyluracil, dihydrouracil, inosine, N6-isopentenyladenine, 1-methyladenine, 1-methylpseudo-uracil, 1-methylguanine, 1-methylinosine, 2,2-dimethylguanine, 2-methyladenine, 2-methylguanine, 3-methylcytosine, 5-methylcytosine, N6-methyladenine, 7-methylguanine, 5-methylaminomethyluracil, 5-methoxyaminomethyl-2-thiouracil, beta-D-mannosylqueosine, 5'-methoxycarbonylmethyluracil, 5-methoxyuracil, 2-methylthio-N6-isopentenyladenine, uracil-5-oxyacetic acid methylester, uracil-5-oxyacetic acid, oxybutoxosine, pseudouracil, queosine, 2-thiocytosine, 5-methyl-2-thiouracil, 2-thiouracil, 4-thiouracil, 5-methyluracil, N-uracil-5-oxyacetic acid methylester, uracil-5-oxyacetic acid, pseudouracil, 2-thiocytosine, and 2,6-diaminopurine.

[0029] The term “therapeutic agent” as used herein refers to a compound that produces a desired therapeutic effect. The therapeutic agent can be selected from the group consisting of a protein, an agonist or an antagonist of an antibody, an antigen, a hormone, an anti-inflammatory agent, an antiviral agent, an anti-bacterial agent, a growth factor, a cytokine, a hormone, an oncogene, a tumor suppressor, a transmembrane receptor, a protein receptor, a serum protein, an adhesion molecule, a neurotransmitter, a morphogenetic protein, a differentiation factor, an enzyme, matrix proteins, and an extracellular matrix protein, iRNA, RNA, or fragment and peptides

thereof. In a preferred embodiment, the therapeutic agent is protein such as the Erythropoietin (EPO) protein. Other examples of suitable proteins include, but are not limited to, insulin protein, pro-insulin protein, Remicade, bone morphogenetic protein (BMPs), Transforming growth factor-beta (TGF-beta), Platelet-derived growth factor (PDGF), cartilage derived morphogenic protein (CDMP), and MP-52.

[0030] In another embodiment, the therapeutic agent is an antibody, an antibody fragment, or a mimetibody. Examples of a useful mimetibody include but are not limited to EPO mimetibody, Remicade mimetibody, BMP mimetibody, cartilage derived morphogenic protein (CDMP) mimetibody and MP-52. In a preferred embodiment, the antibody is the EPO mimetibody.

[0031] In yet another embodiment, the therapeutic agent is a growth factor. Preferred growth factors include, but are not limited to, epidermal growth factor, bone morphogenetic protein, vascular endothelial-derived growth factor, hepatocyte growth factor, platelet-derived growth factor, hematopoietic growth factors, heparin binding growth factor, peptide growth factors, and basic and acidic fibroblast growth factors. In some embodiments it may be desirable to incorporate genes for factors such as nerve growth factor (NGF) or muscle morphogenic factor (MMP), TGF-beta superfamily, which includes BMPs, CDMP, and MP-52. In yet another embodiment, the therapeutic agent is a receptor. Examples of receptors include, but are not limited to, EPO Receptor, B Cell Receptor, Fas Receptor, IL-2 Receptor, T Cell Receptor, EGF Receptor, Wnt, Insulin Receptor, TNF Receptor.

[0032] The terms “modifies” or “modified” “modifying” or “modification” are used interchangeably herein and refer to the up-regulation or down-regulation of the therapeutic agent in a cell associated with a disorder, or at a target region. For example, the genetically modified chondrocyte can be used to express a therapeutic agent associated with a blood disorder, e.g., the EPO protein, by delivering the genetically altered chondrocyte to the liver or kidney, or any tissue or organ with a vascular supply to allow EPO to reach the target site or region. Once the EPO protein is expressed, it can enter the circulatory system and bind to, and alter the function of the EPO receptor

(EPOR). This in turn will cause a change in the environment associated with the EPO receptor, for example by modifying the signal transduction cascade involving the EPO receptor. Thus, the term “modifies” or “modified” also refers to the increase, decrease, elevation, or depression of processes or signal transduction cascades involving the therapeutic agent (e.g., EPO), or a protein associated with the therapeutic agent (e.g., EPOR).

[0033] Modification of the cell may occur directly, for example by overexpressing EPO in a target region. Alternatively, modification of a cell may occur indirectly, for example by the overexpressed EPO interacting with an EPOR that lead to a changes in downstream signal transduction cascades involving the EPOR. Non-limiting examples of modifications include cell proliferation response, cell differentiation, modifications of morphological and functional processes, under- or over- production or expression of a substance or substances by a cell, *e.g.*, a hormone, growth factors, etc, failure of a cell to produce a substance or substances which it normally produces, production of substances, *e.g.*, neurotransmitters, and/or transmission of electrical impulses.

[0034] These terms are also used to describe the effect of the expressed therapeutic agent on the cell, the target region, or the environment surrounding the cell or target region. The therapeutic agent is expressed at a level sufficient to produce a desired therapeutic effect by altering the cell, target region, or the environment surrounding the cell or target region. For example, the expression of EPO in a target region, (e.g., the liver), will produce elevated levels of EPO that alter blood hematocrit, and hemoglobin levels.

[0035] The phrases “an atypical chondrocyte environment,” a “non-chondrocyte typical environment,” “an environment not usually associated with chondrocytes,” and an ectopic site are used interchangeably herein and refer to a surrounding in which chondrocytes are not present. Examples of an environment not usually associated with chondrocytes include the central nervous system (CNS). The CNS which includes the brain and spinal cord, is generally considered immunoprivileged. Other examples of environments that are not usually associated with chondrocytes include solid organs. Examples of solid organs include, but are not limited to, the heart, kidney, liver and

pancreas. Yet another example of an environment not usually associated with chondrocytes, is the reproductive organs. In males, the reproductive organs not associated with chondrocytes are for example, the testis, vas deferens, and the like. In females, the reproductive organs not associated with chondrocytes are, for example, the uterus, fallopian tubes, ovaries and the like. Other examples of an environment not associated with chondrocytes include skin, a subcutaneous pouch, intramuscular and intraperitoneal space.

[0036] The term “biocompatible substrate” or “biocompatible matrix” are used interchangeably herein, and refer to a material into, or onto which a cell population (e.g., a chondrocyte population) can be deposited. The material is suitable for implantation in a subject, and does not cause toxic or injurious effects once implanted in the subject.

[0037] The term “subject” as used herein refers to any living organism capable of eliciting an immune response. The term subject includes, but is not limited to, humans, nonhuman primates such as chimpanzees and other apes and monkey species; farm animals such as cattle, sheep, pigs, goats and horses; domestic mammals such as dogs and cats; laboratory animals including rodents such as mice, rats and guinea pigs, and the like. The term does not denote a particular age or sex. Thus, adult and newborn subjects, as well as fetuses, whether male or female, are intended to be covered.

[0038] The term “vector” as used herein refers to any genetic element, such as a plasmid, phage, transposon, cosmid, chromosome, artificial chromosome, virus, virion, etc., which is capable of replication when associated with the proper control elements and which can transfer gene sequences between cells. Thus, the term includes cloning and expression vehicles, as well as viral vectors.

[0039] The term “transfection” as used herein refers to the uptake of foreign DNA by a cell. A cell has been “transfected” when exogenous DNA has been introduced inside the cell membrane. Such techniques can be used to introduce one or more exogenous DNA moieties, such as a nucleotide integration vector and other nucleic acid molecules, into suitable host cells. The term captures chemical, electrical, and viral-mediated transfection procedures.

[0040] Various aspects of the invention are described in more detail in the following subsections:

I. Culturing and Genetically Altering A Chondrocyte Cell Population

[0041] One aspect of the invention pertains to culturing and genetically altering chondrocytes such that the genetically altered chondrocytes express a therapeutic agent. In one embodiment, the genetically altered chondrocytes are used to produce a therapeutic agent in an environment that is not typically associated with chondrocytes, such as the brain, or solid organs (e.g., heart, kidney, liver). In another embodiment, the genetically altered chondrocytes are used to express a therapeutic agent in an environment associated with chondrocytes, such as the cartilage, tendons, joints, and bones. In such instances, the genetically altered chondrocytes are used exclusively for manufacturing and expressing the therapeutic agent, and not as components of a tissue engineered construct used to repair or replace a damaged cartilage, tendon, joint, or bone.

[0042] There are a number of reasons for using genetically altered chondrocytes. To begin with, chondrocytes have the ability to survive in very harsh conditions such as environments with a low pH, or low oxygen tension. Thus, the genetically altered chondrocyte population has a post-implantation survival advantage, especially when introduced into diseased or injured tissues such as stroke-damaged tissue.

[0043] Furthermore, the genetically altered chondrocytes require no vascular support for survival. This is an important since chondrocytes have a better chance at surviving encapsulation procedures, such as within a gel matrix, as well as implantation procedures. In the past, the size and geometry of cell containing capsules have been limited because most cells depend upon close proximity to vascularity for survival. That is, cells encapsulated in too large a format or in large capsules would have compromised viability because the cells in the center of the implant would not have adequate gas and nutrient exchange.

[0044] In addition, chondrocytes have a uniform phenotype. The tissue from which the cells are isolated is mostly composed of chondrocytes, and it is free of vascular endothelial cells, stromal cells or any other cell that forms the cartilage tissue. The physical appearance of the cartilage tissue is also very distinct from the surrounding tissue, making dissection very easy. These characteristics allow for easy isolation of pure population normal chondrocytes. Once the isolated chondrocytes are placed in tissue culture, they behave similarly to fibroblastic cell lines. The fibroblast-like growth is reversible and the cells can be easily induced to redifferentiate into chondrocytes when placed in anchorage independent conditions such as in agarose or alginate gel suspension. Therefore, immortalized transformed cell lines, which are known to be highly metabolic, with a resultant tendency towards cancerous mutation, are not necessary.

[0045] Chondrocytes typically secrete an extensive extracellular matrix when placed in anchorage independent conditions. This matrix is thought to protect the cells from direct cell-cell contact from the blood supply, thereby delaying or preventing immune rejection. This could provide yet another survival advantage and enable an allogenic or xenogenic implant approach. Allogenic and xenogenic cells could also have a more simple regulatory pathway since they could be seen as temporary, and therefore closer in concept to a device than a permanent tissue transplant.

[0046] Furthermore, when the chondrocytes are placed in suspension during anchorage independent culture, they do not need to form an organized tissue to perform because the secretion of extracellular matrix, which protects against rejection, occurs at the cellular level. Large scale preparation of chondrocyte- containing gels could be performed, and the dose of the therapeutic could be adjusted by varying the amount or size of gel to be implanted without affecting the overall behavior of the implant. In other words, a small and large implant would differ only in the number of encapsulated cells, without affecting the biological functioning of the cells.

[0047] The chondrocytes can be isolated from a variety of sources. For example, embryonic chondrocytes can be isolated from sterna (Leboy *et al.*, (1989) *J. Biol. Chem.*, 264:17281-17286; Sullivan *et al.*, (1994) *J. Biol. Chem.*, 269:22500-22506; and

Bohme *et al.*, (1995) *Exp. Cell Res.*, 216:191-198), and vertebra (Lian *et al.*, (1993) *J. Cellular Biochem.*, 52:206-219), limb bud mesenchymal cells in micromass cultures (Roark *et al.*, (1994) *Develop. Dynam.*, 200:103-116; and Downie *et al.*, (1994) *Dev. Biol.*, 162:195), growth plate chondrocytes in monolayer (Rosselot *et al.*, (1994) *J. Bone Miner. Res.*, 9:431-439; Gelb *et al.*, (1990) *Endocrinology*, 127:1941-1947; and Crabb *et al.* (1990) *J. Bone Mineral Res.*, 5:1105-1112), or pellet cultures (Kato *et al.*, (1988) *Proc. Nat. Acad. Sci.*, 85:9552-9556) have been used to characterize chondrocyte responses to exogenous factors, many of which function in an autocrine manner.

[0048] Chondrocytes can be obtained by a biopsy of cartilaginous tissue from an area treated with local anaesthetic with a small amount of lidocaine injected subcutaneously. The chondrocyte cells from the biopsied tissue can be expanded in culture. The biopsy can be obtained using a biopsy needle, a rapid action needle which makes the procedure quick and simple. In a preferred embodiment, chondrocytes are isolated from donor tissue and large cell banks are carefully characterized and optimized to provide a uniform product.

[0049] Chondrocyte cells obtained by biopsy can be cultured and passaged as necessary. For example, articular cartilage can be aseptically obtained from calf knee joints. Cartilage can be shaved from the end of the bones using a scalpel. The tissue can be finely minced in saline solution and submitted to collagenase and trypsin digestion for several hours at 37°C until the tissue has completely digested and single cells are generated. The chondrocyte cells isolated from the cartilage tissue can then be washed from enzyme with DMEM containing 10% fetal bovine serum, and seeded onto tissue culture plastic dishes using about 5,000 cells to about 10,000 cells per square centimeter. The chondrocyte cells can be cultured in DMEM and 10% fetal calf serum with L-glutamine (292 µg/cc), penicillin (100 U/cc), streptomycin (100 µg/cc) at 37°C in 5% CO₂ with an atmosphere having 100% humidity and expanded in number (*See* FIG. 1). The chondrocyte cells can then be removed from the tissue culture vessel using trypsin/EDTA and passaged into larger tissue culture vessels or encapsulated in gel

suspension. Expanded chondrocyte cells can also be frozen according to standard procedures until needed.

- [0050] Other sources from which chondrocytes can be derived include adipose-derived cells, mesenchymal stem cells, fetal stem cells, marrow-derived stem cells, and other pluripotent stem cells. The chondrocytes can be autogeneic, isogeneic (e.g., from an identical twin), allogeneic, or xenogeneic.
- [0051] A number of studies have been conducted on the isolated chondrocytes, from which has emerged the critical role for a number of growth factors, including basic fibroblast growth factor (bFGF), transforming growth factor beta (TGF β), insulin-like growth factor-1 (IGF-1), and parathyroid hormone (PTH), which regulate chondrocyte proliferation and differentiation. The expression of these factors and their associated receptors are maturation dependent and exquisitely regulated (Bohme, *et al.*, (1992) *Prog. Growth Factor Res.* 4:45-68). Other studies have shown that vitamins A, C, and D are also required for chondrocyte maturation (Leboy *et al.*, (1994) *Microscopy Res. and Technique* 28:483-491; Iwamoto *et al.*, (1993) *Exp. Cell Res.*, 207:413-420; Iwamoto *et al.*, (1993) *Exp. Cell Res.* 205:213-224; Pacifici *et al.*, (1991) *Exp. Cell Res.* 195:38-46; Shapiro *et al.*, (1994) *J. Bone Min. Res.* 9:1229-1237; Corvol *et al.* (1980) *FEBS Lett.* 116:273-276; Gerstenfeld *et al.*, (1990) *Conn. Tiss. Res.* 24:29-39; Schwartz *et al.*, (1989) *J. Bone Miner. Res.* 4:199-207; and Suda, (1985) *Calcif Tissue Int.*, 37:82-90).
- [0052] The chondrocyte cells may be engineered to incorporate a nucleic acid encoding a therapeutic agent such as proteins, antibodies, regulators and cytokines. Other molecules, genes, or nucleic acids that influence cell growth, matrix production, or other cellular functions such as cell cycle may also be used. Nucleic acids may be DNA, RNA, or other nucleotide polymers. Such polymers may include natural nucleosides, nucleoside analogs, chemically modified bases, biologically modified bases, intercalated bases, modified sugars, or modified phosphate groups.
- [0053] In one embodiment, the nucleic acid can be introduced into the chondrocytes as naked DNA, nanocapsules, microspheres, beads, and lipid-based systems such as

liposomes, or carriers such as keyhole limpet hemocyanin (KLH) and human serum albumin (*See e.g.*, U.S. 6,303,379, to Selden, incorporated herein by reference).

[0054] In another embodiment, the chondrocytes may be transfected using vectors engineered to carry a nucleic acid that encodes the therapeutic agent. The nucleic acid sequences can be cloned into the vector using standard cloning procedures known in the art, as described by Maniatis *et al.*, Molecular Cloning: A Laboratory Manual, Cold Springs Laboratory, Cold Springs Harbor, N.Y. (1982), which is hereby incorporated by reference. Suitable vectors include, but are not limited to plasmid vectors such as pRO-EX (Gibco/BRL), pBR322, pBR325, pACYC177, pACYC184, pUC8, pUC9, pUC18, pUC19, pLG339, pR290, pKC37, pKC101, SV 40, pBluescript II SK⁺ or KS⁺ (*See* Stratagene Cloning Systems Catalog from Stratagene, La Jolla, Calif., which is hereby incorporated by reference), pQE, pIH821, pGEX, pET series (*See* Studier *et al.*, Use of T7 RNA Polymerase to Direct Expression of Cloned Genes, Gene Expression Technology vol. 185 (1990), which is hereby incorporated by reference) and any derivatives thereof. In a preferred embodiment, the plasmid vector is pCDNA3.1. In another preferred embodiment, the plasmid vector is pCEP4.

[0055] The gene encoding the therapeutic agent (e.g., EPO) can be operably linked to other elements regulating expression of the gene, including, but not limited to, a promoter, an enhancer sequence, repressor sequence, TATA box, transcription stop sequence, ribosomal binding site, post-transcriptional regulatory element, etc. One of skill in the art would appreciate the variety of elements that may be used in combination with the therapeutic gene.

[0056] Promoters vary in their "strength" (i.e., their ability to promote transcription), and can be constitutive. For the purposes of expressing a therapeutic gene, it is desirable to use strong promoters in order to obtain a high level of transcription and expression of the therapeutic gene. In one embodiment, the promoter is a constitutive promoter that includes, but is not limited to, CMV, RSV promoters, and the like. Other promoters include, but are not limited to, LTR or SV40 promoter, the *E. coli*. lac or trp, T3 and T7 promoters, HSV thymidine kinase, as well as other promoters known to control

expression of genes in prokaryotic or eukaryotic cells. In another embodiment, the promoter is specific for a particular cell type. For example, a promoter is functional in the central nervous system (e.g., glial specific promoters, neuron elonase promoter, and the like); functional in the organs such as the liver (e.g., albumin and alphas antitrypsin promoters, and the like, that are active in hepatocytes); functional in the pancreas (e.g., insulin promoter, pancreatic amylase promoter and the like); or functional in the heart (e.g., ventricular myocyte-specific promoter, alpha-MyHC and beta-MyHC promoter). One skilled in the art will appreciate that the vectors can be readily engineered to include any desired regulatory elements that are required for the specific transcription of the therapeutic gene using standard molecular biology techniques.

[0057] Also within the scope of the invention are biologically active fragments of the therapeutic agent that produce a desired effect. For example, the complete gene for EPO can be transfected into a chondrocyte. Alternatively, active fragments of the gene can be used. Thus, the transfected gene may code for the entire therapeutic agent, or for a biologically active peptide. Also within the scope of the invention are homologous proteins that are at least 50, 75, or 90% homologous to the therapeutic agent. Alternatively, a DNA sequence representing a functional peptide agonist could also be used.

[0058] A variety of gene transfection techniques are known in the art. The nucleic acid sequence can be introduced into cells via transformation, particularly transduction, conjugation, mobilization, or electroporation. For example, viral vectors such as adenovirus are commonly used to insert DNA into a variety of cells. Other transfection methods include electroporation, calcium-phosphate methods, and lipid based methods. (See e.g., Sambrook *et al.*, Molecular Cloning: A Laboratory Manual, 2nd Ed., 1989; Miller and Calos, eds., Gene Transfer Vectors for Mammalian Cells, 1987; Ausubel *et al.*, eds., Current Protocols in Molecular Biology, 1987; each of which is incorporated herein by reference). Both stable transfection and transient expression techniques may be employed, depending on how long the therapeutic gene should be expressed.

[0059] Those chondrocytes that have been genetically altered to carry the plasmid encoding the therapeutic agent, can be selected by any method available to the skilled artisan. In a preferred embodiment, the genetically altered chondrocytes are selected using an antibiotic marker, such as neomycin. This allows for the selection of only those chondrocytes that have been genetically altered. These isolated chondrocytes can then be amplified to provide a population of cells that carries the plasmid encoding the therapeutic agent. These altered chondrocytes retain the phenotype of a typical chondrocytes, but primarily express the therapeutic agent. These genetically altered chondrocyte population does not become a structural part of the cell, target region or the environment surrounding the cell or target region. The genetically altered chondrocytes function only to express the therapeutic agent.

II. Environments and Therapeutic Agents

[0060] The invention pertains to using genetically engineered chondrocytes as vehicles to deliver a therapeutic agent to an environment. In one embodiment, the environment can be one that is not typically associated with chondrocytes, such as the central nervous system, or solid organs such as the heart, liver or kidney. In another embodiment, the environment is one associated with chondrocytes, however, the chondrocytes still have the chondrocyte phenotype and they are used expressly to produce the therapeutic agent. The chondrocytes do not perform the function of cartilage tissue (enabling friction-free articulation), and thus they are not used for tissue repair or construction with a tissue engineered construct. In one embodiment, the genetically altered chondrocytes are engineered to express one therapeutic agent, (e.g., EPO). In another embodiment, the genetically altered chondrocytes are engineered more than one therapeutic agents., for example, two therapeutic agents, three therapeutic agents, or more than three therapeutic agents.

[0061] The genetically altered chondrocytes can be delivered to a cell or target region using known procedures for delivering vectors. For example, the genetically altered chondrocytes can be mixed with a liquid gel and injected to a target region using a surgical syringe. The liquid gel can solidify in situ at the target region. Alternatively, a

chondrocyte-gel matrix solid can be surgically implanted into a target region. The gel matrix solid can be in the form of a thin sheet that can be rolled or folded , and inserted into the target region using a surgical instrument, and allowed to unfold at the target region (e.g., interocular lens). The genetically altered chondrocytes alone (i.e., without being mixed with a substrate), can be injected to a target region.

[0062] Examples of environments not typically associated with chondrocytes include, but are not limited to the following:

(i) *Central Nervous System*

[0063] The genetically altered chondrocytes of the invention can be used to ameliorate or modify the function of cells associated with a neurodegenerative or neurological disorder involving the central nervous system. Regions of the central nervous system that can be targeted by the genetically altered chondrocytes of the invention include the cells in the brain and the spinal cord. Examples of therapeutic agents that can be expressed by genetically altered chondrocytes in the central nervous system include, but are not limited to, receptors (e.g. N-methyl-D-aspartate (NMDA) receptor, GluR receptor (e.g., GluR4, GluR6)); neurotransmitters (e.g., dopamine, acetylcholine, and norepharine); transporters (e.g., glutamate transporters such as excitatory amino acid transporters (EAAT)); growth factors (e.g., neurotrophic factor (GDNF), ciliary derived neuronotrophic factor (CNTF), brain derived neuronotrophic factor (BDNF), neuronotrophin-3 (NT3), epidermal growth factor (EGF), fibroblast growth factor (FGF), transforming growth factor-a (TGF-a), transforming growth factor-b (TGF-b), platelet derived growth factor (PDGF)).

a) *Suitable Models of Neurodegenerative Diseases*

(i) *Huntington's disease*

[0064] The genetically altered chondrocytes of the invention can be used to ameliorate or modify neurodegeneration in a subject with neurodegenerative diseases such as Huntington's disease. Models of Huntington's disease have been developed in several

different animals, for example in the rat (Isacson *et al.* (1985) *Neuroscience* 16:799-817), monkey (Kanazawa, *et al.* (1986) *Neurosci. Lett.* 71:241-246), and baboon (Hantraye. *et al.* (1992) *Proc. Natl. Acad. Sci. USA* 89:4187-4191; Hantraye, *et al.* (1990) *Exp. Neurol.* 108:91-014; Isacson, *et al.* (1989) *Exp. Brain Res.* 75(1):213-220). These models of Huntington's disease have been described as providing effective therapeutic models that are predictive of therapeutic efficacy in humans.

[0065] Neurodegeneration in Huntington's disease typically involves degeneration in one or both nuclei forming the striatum or corpus striatum, the caudate nucleus and putamen. Administration of the genetically altered chondrocytes that express a therapeutic agent to these regions may modify the function of these regions. The genetically altered chondrocytes may be delivered to these regions using a liquid polymer gel comprising the genetically altered chondrocytes, and delivered using standard stereotactic delivery methods to the specific regions of the brain. The therapeutic effects of expressing the therapeutic agent using genetically altered chondrocytes, can be determined by morphological and immunohistochemical studies. Behavioral tests can also be performed using standard techniques, such as the maze test.

(ii) *Parkinson's disease*

[0066] Parkinson's disease in humans primarily affects subcortical structures, especially the substantia nigra and locus caeruleus. It is characterized by the loss of dopamine neurons in the substantia nigra, which have the basal ganglia as their major target organ. Several animal models of Parkinson's disease have been generated in which effective therapies are indicative of therapeutic efficacy in humans. These animal models include three rat models (the rats having lesions in substantia nigral dopaminergic cells caused by treatment with 6-hydroxydopamine, 1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine (MPTP), or surgical transection of the nigral striatal pathway) (*See, e.g.* Björklund *et al.* (1982) *Nature* 298:652-654), a rhesus monkey model (the monkeys having lesions in substantia nigral dopaminergic cells caused by treatment with MPTP) (*See, e.g.*, Smith, *et al.* (1993) *Neuroscience* 52):7-16; Bakay *et al.* (1985) *Appl. Neurophysiol.* 48:358-361; Zamir. *et al.* (1984) *Brain Res.* 322:356-360), and a sheep model (the sheep having

lesions in substantia nigral dopaminergic cells caused by treatment with MPTP) (Baskin, *et al.* (1994) *Life Sci.* 54:471-479). In one embodiment, the genetically altered chondrocytes can be modified to express a therapeutic agent (e.g., GABA) that ameliorates, or modifies the function of cells associated with Parkinson's disease. The therapeutic effect can be determined as described above for Huntington's disease.

b) Autoimmune disorders

(i) *Diabetes*

[0067] The genetically altered chondrocytes of the invention can be used to ameliorate or modify autoimmune diseases such as diabetes. A summary of insulin-dependent diabetes mellitus and its animal models is described by Wong *et al.* (1999) *Curr Opin Immunol* 11:643-647. A few autoantigens have been associated with Type I diabetes mellitus, for example, insulin (Palmer *et al.* (1983) *Science* 222:1337-1339), glutamic acid decarboxylase (GAD) (Baekkeskov *et al.* (1990) *Nature* 347:151-156) and carboxypeptidase H (Castano. *et al.* (1991) *J. Clin. Endocr. Metab.* 73:1197-1201), and the glycolipids GT3 (Gillard, *et al.* (1989) *Journal Immunol. Methods* 142:3826-3832) and GM2-1 (Dotta, *et al.* (1992) *Endocrinology* 130:37-42) and PM-1 (U.S. 5,908,627). These models can be used to investigate the effect of genetically altered chondrocytes that express a therapeutic agent (e.g., insulin) on diabetes in the animal.

(ii) *Rheumatoid Arthritis*

[0068] The genetically modified chondrocytes of the invention can also be implanted in a patient to treat a disease such as Rheumatoid arthritis. In this embodiment, chondrocytes are implanted either in or close to the joint capsule for the treatment of specific joint that is affected by Rheumatoid arthritis, or in an ectopic site for a systemic delivery to all joints of an anti-inflammatory therapeutic agent. Examples of useful anti-inflammatory therapeutic agents that can be expressed by the genetically modified chondrocytes to treat Rheumatoid arthritis include, but are not limited to TNF-alpha antagonist and Remicade.

(c) Reproduction

[0069] Substances involved in reproduction can also be modified using the genetically altered chondrocytes of the invention. Suitable animal models for reproduction are Sprague-Dawley rats, which are readily available. For example, modifying the function of luteinizing hormone-releasing hormone (LHRH), a hormone regulated by the hypothalamus and involved in the stimulation of ovulation and uterine growth (Fueshko *et al.* (1994) *Dev Biol* 166:331-348; Hahn *et al.* (1984) *Endocr Res*, 10:123-138). Luteinizing hormone-releasing hormone also plays a role in male sterility by inhibiting the action of luteinizing hormone-releasing hormone with a synthetic decapeptide (Carelli (1982) *Proc Natl. Acad. Sci. U S A* 79:5392-5395).

[0070] Alternatively, the genetically altered chondrocytes can be used to deliver estrogen for post-menopausal hormone therapy in women. These genetically altered chondrocytes can be delivered to the uterus, fallopian tubes, ovaries and the like reproductive organs. Further, since diffusible factors such as hormones, need not be delivered to a specific target site, unless there is a systemic toxic or unwanted side effect, alternative delivery options include local delivery accomplished by injection through a syringe, surgical implantation, or endoscopic delivery through a trochar. The genetically altered chondrocytes may also be used for sterilization purposes by delivering a sterilization agent that causes sterility in males. The genetically altered chondrocytes that express the sterilization agent can be delivered, for example to the testis. Other male reproductive organs that can be targeted by the genetically altered chondrocytes include, but are not limited to, testis, urethra, and ureter.

(d) Blood Related disorders

[0071] The genetically altered chondrocytes can be used to express therapeutic agents such as erythropoietin (EPO). EPO is a glycoprotein hormone produced primarily by cells of the peritubular capillary endothelium of the kidney, and is responsible for the regulation of red blood cell production. Secondary amounts of the hormone are synthesized in liver hepatocytes of healthy adults. In premature as well as full term

infants, the liver is the primary site of EPO production. The kidney becomes the primary site of EPO synthesis shortly after birth. EPO production is stimulated by reduced oxygen content in the renal arterial circulation. Circulating EPO binds to EPO receptors on the surface of erythroid progenitors resulting in replication and maturation to functional erythrocytes by an incompletely understood mechanism.

[0072] Clinical conditions that give rise to tissue hypoxia including anemia, lung disease, or cyanotic heart disease, lead to increased levels of serum EPO. Low EPO levels are observed in patients with anemia, patients with cancer, as well as those with rheumatoid arthritis, HIV infection, ulcerative colitis, and sickle cell anemia. Suppression of EPO synthesis by inflammatory cytokines (e.g., IL-1, TNF-alpha) is believed to occur in certain chronic diseases or cancer.

[0073] In contrast, elevation of EPO levels can occur in association with renal diseases such as hydronephrosis or cysts, or certain tumors, resulting in erythrocytosis. Examples include renal cell carcinoma (hypernephroma), hepatocellular carcinoma, and adrenal gland tumors. Certain bone marrow disorders, such as myelodysplastic syndrome and aplastic anemia, may also be associated with high serum levels of EPO. In the setting of bone marrow disease, high serum EPO levels are presumably due to the reduction in the number of EPO receptor bearing cells, thereby allowing serum levels to rise. Thus, genetically modified chondrocytes can also be used to express EPO antibody to interact with the elevated EPO to reduce the level.

[0074] Suitable in an animal model of anemia that can be used to test the genetically modified chondrocytes are available (*See e.g.*, Hamamori *et al.*, (1995), *J. Clinical Investigation*, 95:1808-1813, Osborne *et al.*, (1995) *Proc. Natl. Acad. Sci.*, USA, 92:8055-8058). The genetically modified chondrocytes expressing EPO can be implanted into the anemic animal and determining the level of EPO and the hematocrit of the treated animal can be measured over time.

(e) Allergies

[0075] The genetically modified chondrocytes of the invention can also be implanted in a patient to treat allergies by effecting the *in vivo* production of the allergens, or their antibodies through the genetically modified chondrocytes. Through controlled expression of the allergens, or their antibodies, the patient gradually develops IgG antibodies that block the IgE antibodies which result in long term relief from allergies.

(f) Pain management

[0076] Pain management can be effected through the genetically modified chondrocytes as well by modifying the chondrocytes to express opiates or endorphins. The genetically modified chondrocytes that express such pain mediating substances would be implanted in tissue such as the brain. In addition, the chondrocytes can be modified to express nociceptive pain relievers, and the modified chondrocytes could be implanted locally, at the site of the injury or disease causing pain.

(g) Cancer Treatment

[0077] Cancer is a disease that is characterized by uncontrolled growth of abnormal or cancerous cells, in most instances as a result of an altered genome in a single abnormal cell. The alteration in the genome is caused by a mutation in one or more genes wherein the probability of the occurrence of a mutation is increased by a variety of factors including (i) ionizing radiation, (ii) exposure to chemical substances known as carcinogens, (iii) some viruses, (iv) physical irritation, and (v) hereditary predisposition.

[0078] The genetically modified chondrocytes can be used to deliver therapeutic agents that enhance a subject's immune response to invading metastases or to either directly or indirectly suppress cancerous cell growth. Such therapeutic agents include, but are not limited to, various cytokines such as interleukin-2 (IL-2), granulocyte-macrophage colony stimulating factor (GM-CSF), interleukin-12 (IL-12) and interferon-gamma (IFN-gamma), anti-angiogenic molecules and tumor associated antigens (Anderson *et al.*, (1990) *Cancer Res.*, 50: 1853, Stoklosa, *et al.*, (1998) *Ann Oncol.*, 9:63, Leibson, *et*

al., (1984) *Nature*, 309:799, Book, *et al.*, (1998) *Semin. Oncol.* 25:381, Salgaller, *et al.*, (1998) *J. Surg. Oncol.*, 68: 122, Griscelli, *et al.*, (1998) *Proc. Natl. Acad. Sci. USA*, 95: 6367).

[0079] Suitable models of tumors are available, for example, the mouse tumor model (See e.g., Hearing *et al.*, (1986) *J. Immunol.*, 137: 379). Therapeutic doses of anti-tumor molecules can be delivered in a mouse tumor model using the genetically altered chondrocytes. In vivo tissue or serum levels of recombinant molecules are measured at varying time points following implantation and the effects on tumor development and animal survival are followed over time. Other art-accepted animal models of cancer have been described in Hearing, (1986) *J. Immunol.*, 137:379, Stoklosa *et al.*, (1998) *Ann. Oncol.*, 9:63, Carson *et al.*, (1998) *J. Surg. Res.*, 75:97, Maurer-Gebhard *et al.*, (1998) *Cancer Res.*, 58:2661 and Takaori-Kondo *et al.*, (1998) *Blood* 91:4747).

[0080] Therapeutic efficacy of treatment of cancer can be determined by measuring changes in clinical parameters such as tumor shrinkage (e.g. at least 5-10% and preferably 25-100%) and/or extended animal survival time.

(h) Solid Organ Treatment

[0081] The genetically modified chondrocytes can be used to deliver therapeutic agents (directly or in close proximity) to a region in a solid organ such as the heart, kidney, or liver.

III. Biocompatible Substrates

[0082] The genetically altered chondrocytes of the invention can be delivered to a desired environment by using biocompatible substrates. In one embodiment of the present invention, the substrate can be formed from a biocompatible polymer. A variety of biocompatible polymers can be used to make the biocompatible tissue implants or substrates according to the present invention. The biocompatible polymers can be synthetic polymers, natural polymers or combinations thereof. As used herein the term "synthetic polymer" refers to polymers that are not found in nature, even if the polymers

are made from naturally occurring biomaterials. The term “natural polymer” refers to polymers that are naturally occurring. In embodiments where the substrate includes at least one synthetic polymer, suitable biocompatible synthetic polymers can include polymers selected from the group consisting of aliphatic polyesters, poly(amino acids), copoly(ether-esters), polyalkylenes oxalates, polyamides, tyrosine derived polycarbonates, poly(iminocarbonates), polyorthoesters, polyoxaesters, polyamidoesters, polyoxaesters containing amine groups, poly(anhydrides), polyphosphazenes, and blends thereof. Suitable synthetic polymers for use in the present invention can also include biosynthetic polymers based on sequences found in collagen, elastin, thrombin, fibronectin, starches, poly(amino acid), poly(propylene fumarate), gelatin, alginate, pectin, fibrin, oxidized cellulose, chitin, chitosan, tropoelastin, hyaluronic acid, ribonucleic acids, deoxyribonucleic acids, polypeptides, proteins, polysaccharides, polynucleotides and combinations thereof.

[0083] For the purpose of this invention aliphatic polyesters include, but are not limited to, homopolymers and copolymers of lactide (which includes lactic acid, D-,L- and meso lactide); glycolide (including glycolic acid); ϵ -caprolactone; p-dioxanone (1,4-dioxan-2-one); trimethylene carbonate (1,3-dioxan-2-one); alkyl derivatives of trimethylene carbonate; δ -valerolactone; β -butyrolactone; γ -butyrolactone; ϵ -decalactone; hydroxybutyrate; hydroxyvalerate; 1,4-dioxepan-2-one (including its dimer 1,5,8,12-tetraoxacyclotetradecane-7,14-dione); 1,5-dioxepan-2-one; 6,6-dimethyl-1,4-dioxan-2-one; 2,5-diketomorpholine; pivalolactone; α , α diethylpropiolactone; ethylene carbonate; ethylene oxalate; 3-methyl-1,4-dioxane-2,5-dione; 3,3-diethyl-1,4-dioxan-2,5-dione; 6,6-dimethyl-dioxepan-2-one; 6,8-dioxabicyclooctane-7-one and polymer blends thereof. Aliphatic polyesters used in the present invention can be homopolymers or copolymers (random, block, segmented, tapered blocks, graft, triblock, etc.) having a linear, branched or star structure. Poly(iminocarbonates), for the purpose of this invention, are understood to include those polymers as described by Kemnitzer and Kohn, in the Handbook of Biodegradable Polymers, edited by Domb, *et. al.*, Hardwood Academic Press, pp. 251-272 (1997). Copoly(ether-esters), for the purpose of this invention, are understood to include those copolyester-ethers as described in the Journal of Biomaterials

Research, Vol. 22, pages 993-1009, 1988 by Cohn and Younes, and in Polymer Preprints (ACS Division of Polymer Chemistry), Vol. 30(1), page 498, 1989 by Cohn (e.g., PEO/PLA). Polyalkylene oxalates, for the purpose of this invention, include those described in U.S. Patent Numbers 4,208,511; 4,141,087; 4,130,639; 4,140,678; 4,105,034; and 4,205,399. Polyphosphazenes, co-, ter- and higher order mixed monomer based polymers made from L-lactide, D,L-lactide, lactic acid, glycolide, glycolic acid, para-dioxanone, trimethylene carbonate and ϵ -caprolactone such as are described by Allcock in The Encyclopedia of Polymer Science, Vol. 13, pages 31-41, Wiley Intersciences, John Wiley & Sons, 1988 and by Vandorpe, *et al* in the Handbook of Biodegradable Polymers, edited by Domb, *et al.*, Hardwood Academic Press, pp. 161-182 (1997). Polyanhydrides include those derived from diacids of the form $\text{HOOC-C}_6\text{H}_4\text{-O-(CH}_2\text{)}_m\text{-O-C}_6\text{H}_4\text{-COOH}$, where "m" is an integer in the range of from 2 to 8, and copolymers thereof with aliphatic alpha-omega diacids of up to 12 carbons. Polyoxaesters, polyoxaamides and polyoxaesters containing amines and/or amido groups are described in one or more of the following U.S. Patent Nos. 5,464,929; 5,595,751; 5,597,579; 5,607,687; 5,618,552; 5,620,698; 5,645,850; 5,648,088; 5,698,213; 5,700,583; and 5,859,150. Polyorthoesters such as those described by Heller in Handbook of Biodegradable Polymers, edited by Domb, *et al.*, Hardwood Academic Press, pp. 99-118 (1997).

[0084] As used herein, the term "glycolide" is understood to include polyglycolic acid. Further, the term "lactide" is understood to include L-lactide, D-lactide, blends thereof, and lactic acid polymers and copolymers.

[0085] Elastomeric copolymers are also particularly useful in the present invention. Suitable elastomeric polymers include those with an inherent viscosity in the range of about 1.2 dL/g to 4 dL/g, more preferably about 1.2 dL/g to 2 dL/g and most preferably about 1.4 dL/g to 2 dL/g as determined at 25°C in a 0.1 gram per deciliter (g/dL) solution of polymer in hexafluoroisopropanol (HFIP). Further, suitable elastomers exhibit a high percent elongation and a low modulus, while possessing good tensile strength and good recovery characteristics. In the preferred embodiments of this

invention, the elastomer exhibits a percent elongation greater than about 200 percent and preferably greater than about 500 percent. In addition to these elongation and modulus properties, suitable elastomers should also have a tensile strength greater than about 500 psi, preferably greater than about 1,000 psi, and a tear strength of greater than about 50 lbs/inch, preferably greater than about 80 lbs/inch.

[0086] Exemplary biocompatible elastomers that can be used in the present invention include, but are not limited to, elastomeric copolymers of ϵ -caprolactone and glycolide (including polyglycolic acid) with a mole ratio of ϵ -caprolactone to glycolide of from about 35:65 to about 65:35, more preferably from 45:55 to 35:65; elastomeric copolymers of ϵ -caprolactone and lactide (including L-lactide, D-lactide, blends thereof, and lactic acid polymers and copolymers) where the mole ratio of ϵ -caprolactone to lactide is from about 35:65 to about 65:35 and more preferably from 45:55 to 30:70 or from about 95:5 to about 85:15; elastomeric copolymers of p-dioxanone (1,4-dioxan-2-one) and lactide (including L-lactide, D-lactide, blends thereof, and lactic acid polymers and copolymers) where the mole ratio of p-dioxanone to lactide is from about 40:60 to about 60:40; elastomeric copolymers of ϵ -caprolactone and p-dioxanone where the mole ratio of ϵ -caprolactone to p-dioxanone is from about from 30:70 to about 70:30; elastomeric copolymers of p-dioxanone and trimethylene carbonate where the mole ratio of p-dioxanone to trimethylene carbonate is from about 30:70 to about 70:30; elastomeric copolymers of trimethylene carbonate and glycolide (including polyglycolic acid) where the mole ratio of trimethylene carbonate to glycolide is from about 30:70 to about 70:30; elastomeric copolymers of trimethylene carbonate and lactide (including L-lactide, D-lactide, blends thereof, and lactic acid polymers and copolymers) where the mole ratio of trimethylene carbonate to lactide is from about 30:70 to about 70:30; and blends thereof. Examples of suitable biocompatible elastomers are described in U.S. Patent No. 5,468,253.

[0087] In one embodiment, the elastomer is a copolymer of 35:65 ϵ -caprolactone and glycolide, formed in a dioxane solvent and including a polydioxanone mesh. In another embodiment, the elastomer is a copolymer of 40:60 ϵ -caprolactone and lactide with a

polydioxanone mesh. In yet another embodiment, the elastomer is a 50:50 blend of a 35:65 copolymer of ϵ -caprolactone and glycolide and 40:60 copolymer of ϵ -caprolactone and lactide. The polydioxanone mesh may be in the form of a one layer thick two-dimensional mesh or a multi-layer thick three-dimensional mesh.

[0088] In another embodiment, the substrate can be in the form of an injectable gel matrix. The gel matrix can be a biological or synthetic hydrogel, including alginate, cross-linked alginate, hyaluronic acid, collagen gel, fibrin glue, fibrin clot, poly(N-isopropylacrylamide), agarose, chitin, chitosan, cellulose, polysaccharides, poly(oxyalkylene), a copolymer of poly(ethylene oxide)-poly(propylene oxide), poly(vinyl alcohol), polyacrylate, platelet rich plasma (PRP) clot, platelet poor plasma (PPP) clot, Matrigel, or blends thereof.

[0089] The gel matrix is selected to have properties that allow the therapeutic agent to be expressed within the gel matrix, as well as allowing the expressed therapeutic agent to diffuse out of the gel matrix into the surrounding environment.

[0090] Examples of gel matrices that may be used include, but are not limited to, collagen gel, fibrin glue, polyglycolic acid, polylactic acid, polyethylene oxide gel, alginate or calcium alginate gel, poly-(2-hydroxyethyl methacrylate) (i.e., a hydrogel), polyorthoester, hyaluronic acid, polyanhydride, chitosan, gelatin, agarose, and other bioresorbable and biocompatible materials such as those described in EP 0705878 A2. To promote chondrocyte proliferation and function, the biological gel can additionally contain appropriate nutrients (e.g., serum, salts such as calcium chloride, ascorbic acid, and amino acids) and growth factors (e.g., somatomedin, basic fibroblast growth factor, transforming growth factor- β , cartilage growth factor, bone-derived growth factor, or a combination thereof).

[0091] Polysaccharides are a class of macromolecules of the general formula $(CH_2O)_n$ which are also useful as the hydrogel substrate in the present invention. Polysaccharides include several naturally occurring compounds, e.g., agarose, alginate and chitosan.

[0092] Agarose is a clear, thermoreversible hydrogel made of polysaccharides, mainly the alternating copolymers of 1,4 linked and 3,6-anhydro- α -L-galactose and 1,3 linked β -D-galactose. Two commercially available agaroses are SeaPrepTM and SeaPlaqueTM agarose (FMC Corp. Rockland, Me.). The thermoreversible properties of agarose gels make it possible for agarose to be a liquid at room temperature allowing for easy mixing of cell-gel solution and then cooling to 4°C. causes gelation and entrapment of cells. This is a comparatively benign process, free of chemicals toxic to the cells.

[0093] The agarose concentration can be about 0.50 to 2% (w/v), most preferably about 1.0%. In any event, the concentration of agarose should be sufficient to permit chondrocyte encapsulation at a concentration that varies in the range of about 10^4 cells/ml to 10^7 cells/ml, and more preferably in the range of about 10^5 to 10^6 cells/ml.

[0094] Alginate is a carbohydrate polymer isolated from seaweed, which can be crosslinked to form a hydrogel by exposure to a divalent cation such as calcium, as described, for example in WO 94/25080, the disclosure of which is incorporated herein by reference. The modified alginate solution is mixed with the cells to be implanted to form a suspension. Then the suspension is injected directly into a patient prior to crosslinking of the polymer to form the hydrogel containing the cells. The suspension then forms a hydrogel over a short period of time due to the presence *in vivo* of physiological concentrations of calcium ions (*See e.g.*, U.S. Pat. No. 4,352,883 to Lim, incorporated herein by reference).

[0095] In general, the polymers that make up the biological gels are at least partially soluble in aqueous solutions, such as water, buffered salt solutions, or aqueous alcohol solutions. Methods for the synthesis of the polymers are known to those skilled in the art (*See e.g.*, Concise Encyclopedia of Polymer Science and Polymeric Amines and Ammonium Salts, E. Goethals, editor (Pergamen Press, Elmsford, N.Y. 1980)). Naturally occurring and synthetic polymers may be modified using chemical reactions available in the art and described, for example, in March, "Advanced Organic Chemistry," 4th Edition, 1992, Wiley-Interscience Publication, New York.

- [0096] Water soluble polymers with charged side groups may be crosslinked by reacting the polymer with an aqueous solution containing ions of the opposite charge, either cations if the polymer has acidic side groups or anions if the polymer has basic side groups. Examples of cations for crosslinking of the polymers with acidic side groups to form a hydrogel are monovalent cations such as sodium, and multivalent cations such as copper, calcium, aluminum, magnesium, strontium, barium, and tin, and di-, tri- or tetra-functional organic cations such as alkylammonium salts. Aqueous solutions of the salts of these cations are added to the polymers to form soft, highly swollen hydrogels and membranes. The higher the concentration of cation, or the higher the valence, the greater the degree of cross-linking of the polymer. Additionally, the polymers may be crosslinked enzymatically, e.g., fibrin with thrombin.
- [0097] Several physical properties of the biological gels are dependent upon gel concentration. Increase in gel concentration may change the gel pore radius, morphology, or its permeability to different molecular weight proteins. Gel pore radius determination can be effected by any suitable method, including hydraulic permeability determination using a graduated water column, transmission electron microscopy and sieving spheres of known radius through different agar gel concentrations (*See, e.g., Griess et al., (1993) Biophysical J., 65:138-48*).
- [0098] A variety of other suitable biological gels are also known. The polymer can be mixed with cells for implantation into the body and can be crosslinked to form a hydrogel matrix containing the cells either before or after implantation in the body. A hydrogel is defined as a substance formed when an organic polymer (natural or synthetic) is crosslinked via covalent, ionic, or hydrogen bonds to create a three-dimensional open-lattice structure which entraps water molecules to form a gel.
- [0099] One skilled in the art will appreciate that the volume or dimensions (length, width, and thickness) of the biological gel comprising the chondrocytes can be selected based on the region or environment into which the biological gel substrate is to be implanted. In one embodiment, the biological gel has a length (defined by a first and second long end) of about 10 cm to about 30 cm. The biological gel can further have a

length of about 15 cm to about 25 cm. In a preferred embodiment, the biological gel has a length of about 20 cm. In another embodiment, the biological gel has a width (defined by a first and second short end) of about 0.5 cm to about 4.0 cm. The biological gel can further have a width of about 1.0 cm to about 3.0 cm. In a preferred embodiment, the biological gel has a biocompatible substrate with width of about 2.0 cm.

IV. Manufacturing of Therapeutic Agents Using Genetically Altered Chondrocytes

[00100] In another aspect, the invention pertains to using the genetically altered chondrocytes for large scale *in vitro* preparation of therapeutic agents. For example, liter scale production (e.g., several liters) could be effected with expansion and maintenance of chondrocytes on microcarrier beads. Chondrocyte cells could be genetically manipulated to express a therapeutic molecule of commercial value, then expanded and seeded onto microcarrier-bead containing bioreactor. Alternatively, chondrocytes could be seeded directly onto microcarrier beads and expanded directly in bioreactors.

[00101] The following examples are illustrative of the principles and practice of this invention. Numerous additional embodiments within the scope and spirit of the invention will become apparent to those skilled in the art.

Examples

Example 1: *In vitro* Isolation and Culturing of Chondrocyte Cells

[00102] This example describes one of many possible methods of isolating and culturing chondrocyte cells. Articular cartilage was aseptically obtained from calf knee joints. Cartilage was shaved from the end of the bones using a scalpel. The tissue was finely minced in saline solution and submitted to collagenase and trypsin digestion for several hours at 37°C until the tissue was completely digested and single cells were generated. The chondrocyte cells isolated from the cartilage tissue were then washed from enzyme and seeded onto tissue culture plastic dishes at a concentration of about 10,000 cells/cm².

The chondrocyte cells were expanded in 10% FBS containing DMEM culture medium. Following expansion, the chondrocytes can be released from the vessel using a trypsin/EDTA treatment, centrifuged and concentrated or diluted to a desired concentration to achieve for example a seeding density of approximately 5,000 cells to about 10,000 cells per square centimeter when plated onto culture dishes. Alternatively, the expanded chondrocyte cells can be frozen according to standard procedures until needed.

Example 2: *In vitro* Transfection of Chondrocyte Cells and Expression of a Marker Protein.

[00103] This example described the techniques used to transfect chondrocytes with a marker protein, Green fluorescent protein (GFP). A DNA vector carrying a reporter gene is used to establish proof of concept for the utility of normal articular chondrocytes as a drug delivery system for therapeutic application in ectopic sites. As a model, a DNA vector (pTracer-SV40) carrying a gene for green fluorescent protein was used as a surrogate to model a protein not normally present in chondrocytes, and of therapeutic value. If chondrocytes can be transfected by the model vector and expressed the foreign protein, it would demonstrate the ability of using this system for therapeutic protein. In the following example, a lipid formulation from Stratagene (GeneJammer) was used to introduce the foreign DNA into chondrocytes. Any other reagent or physical means of introducing DNA into cell would serve the same purpose.

[00104] Exponentially growing chondrocytes were seeded onto 35 mm dishes at a density of 1.5 to 3.7×10^6 cells in 10% FBS containing DMEM. In separate plastic tube, serum-free medium was combined with transfection reagent (GeneJammer from Stratagene) and incubated with the chondrocytes for 5–10 minutes. Plasmid DNA (pTracer-SV40 from Invitrogen) was mixed with the chondrocytes, and the mixture further incubated for 5-10 minutes. The transfection mixture was then added to the 35 mm dishes and incubated for at least 3 hours at 37°C. Fresh media (10% FBS containing DMEM) was then added and the cells are fed every 2-3 days with fresh serum containing media.

[00105] In order to identify transfected chondrocytes, the culture chondrocyte cells were observed under fluorescent light. To facilitate this, the culture media was removed and replaced with phosphate buffered saline solution. The cultured chondrocyte cells were examined by fluorescence microscopy. Positive chondrocyte cells were identified as those that incorporated the plasmid, expressed GFP, and fluoresced green under the microscope, as shown in FIG. 2.

[00106] The results illustrate the ability of introducing and expressing a foreign protein in articular chondrocytes. These results further show that chondrocytes provide a robust, stable cell for expression of a heterologous protein.

Example 3: *In vitro* Transfection of Human and Bovine Chondrocyte Cells and Expression of EPO protein

[00107] This example describes the techniques used to transfect chondrocytes with a therapeutic agent, human erythropoietin (EPO).

[00108] An EPO vector was generated which comprised the EPO gene (Genbank Accession No. 182198) inserted into the commercially available pSG5 backbone (Stratagene Inc.). The pSG5 plasmid contains ampicillin and kanamycin as a selection marker for bacteria. This construct also contains F1 filamentous phage origin and SV40 promoter for better expression. The 584 base pair EPO fragment was cloned into the NCO/Bam H1site site of pSG5. The size of this vector was about 4.6 kb.

[00109] A second EPO vector was generated which comprised the EPO gene inserted into the commercially available pCDNA3.1 backbone (Invitrogen Life Technologies). This particular construct has the antibiotic Neomycin as a selection marker for mammalian cells.

[00110] Each of the EPO vectors was transfected into human chondrocytes using FuGENE 6, a commercially available lipid transfection agent (Roche Diagnostics Corporation). Primary human chondrocytes were passaged once, then seeded onto 35 mm plates at a density of 250,000 cells/plate in 10% FBS containing DMEM. The

transfection reagents were combined in serum free medium at a ratio of 3 μ l FuGENE to 1 μ g plasmid and incubated for 15 minutes at room temperature. The resulting transfection mixture was then added dropwise to the chondrocyte plates, with a total of 1.0 μ g of EPO plasmid added to each plate. The cell cultures were incubated at 37°C. Supernatant was collected, in aliquots of 0.5 ml, at 20, 48, 72 and 96 hours and stored at 4°C.

[00111] For this experiment, two control samples were prepared. The first control comprised chondrocytes which were transfected with a gene encoding an EPO mimetibody. The second control comprised cells to which no reagents were added. The above transfection procedure was repeated for human and bovine chondrocytes, with similar cell density, reagent concentrations and control conditions.

[00112] Expression of EPO was determined by measuring the supernatant EPO concentration synthesized by the chondrocytes using a commercially available ELISA kit which is specific to EPO (Quantikine IVD, R&D Systems Inc.). Absorption at 450 nm was measured to determine the amount of bound protein on the ELISA plates.

[00113] FIGS. 3a and b shows that, for both human and bovine chondrocytes, neither control samples exhibited significant EPO expression, while both of the EPO transfection constructs resulted in significant EPO expression. Expression of human EPO by both human and bovine chondrocytes demonstrates the feasibility of allogeneic and xenogenic approaches to chondrocyte-based *in vivo* therapeutic delivery.

Example 4: *In vitro* Transfection of Human Chondrocyte Cells and Expression of EPO mimetibody.

[00114] This example described the techniques used to transfect chondrocytes with a therapeutic agent, the EPO mimetibody (mEPO). This compound is designed to mimic the binding region of the EPO protein, thereby providing the same therapeutic function as EPO when it attaches to the EPO receptor and activates it.

[00115] A construct was developed comprising the mEPO gene inserted into the commercially available pCDNA3.1 backbone (Invitrogen Life Technologies). This particular construct has the antibiotic, Neomycin as a selection marker for mammalian cells, and Ampicillin as a selection marker for bacteria. The size of this vector construct was about 6 kb. Another construct was developed comprising the mEPO gene inserted into the commercially available pCEP4 backbone (Invitrogen Life Technologies). This construct has hygromycin as a selection marker for mammalian cells, and contains EBV replication origin and nuclear antigen (EBNA-1) for better expression. The size of this vector is about 11 kb.

[00116] Each plasmid encoding mEPO was transfected into human chondrocytes using the method outlined in Example 3. Control samples comprised chondrocytes transfected with human EPO, as well as cells to which no reagents were added.

[00117] Expression of mEPO was measured using an ELISA which is specific to the human IgG region of the mimetibody. After 96 hours of transfection, EPO mimetibody expression was detected at a level of 18 ng/ml. As shown in FIG. 4, this expression level was substantially higher than the baseline mEPO level measured for control samples. Collectively, these results demonstrate that chondrocytes can be used to express a therapeutic agents such as EPO and mEPO

Example 5: Creating Chondrocyte-Gel Substrates

[00118] This Example describes how to formulate biological gel matrix substrates comprising genetically altered chondrocytes that express a therapeutic agent. Chondrocytes growing in monolayer (FIG 5A) were released from the culture dish using trypsin/EDTA. The cells were counted and suspended in low melting agarose at 40°C prepared in serum free medium such that the final concentration of cells was 100,000/ml of agarose gel. 3 ml of gel was dispensed into a 30mm dish and allowed to set at room temperature. The gel was then overlayed with an equal volume of 10% FBS containing culture medium. The media is replenished every 2 to 3 days and cultures maintained for several weeks. After a few weeks, colonies of differentiating chondrocytes can be

observed (FIG. 5B). The gels were fixed in formalin 6 weeks after initial suspension and stained with alcian blue. Cartilage matrix deposited by the chondrocytes stains blue and indicates cartilage differentiation (FIG. 5C). Monitoring of therapeutic protein expression could be performed by sampling the culture media overtime. Establishing a delivery dose from such agarose suspended chondrocytes could be done by harvesting different size disks generated for example with a biopsy punch.

Example 6: Use of Chondrocytes to Express a EPO or mEPO in a Non-typical Chondrocyte Environment for a Blood Disorder

[00119] This example describes the use chondrocytes that have been genetically altered to express EPO or mEPO in an *in vivo* system. The chondrocytes were genetically altered as described in Examples 3 and 4 to express EPO or mEPO, and placed into biological gel matrix substrates as described in Example 5. Slices of the solid gel, or a liquid gel that solidifies on contact, can be placed into an animal model of anemia (See Osborn *et al*, Supra), and the amelioration of anemia was observed by measuring the hemocrit levels of the blood.

Example 7: Use of Chondrocytes to Express Therapeutic Agent in a Non-typical Chondrocyte Environment for an Autoimmune Disorder

[00120] This example describes the use chondrocytes that have been genetically altered to express a therapeutic agent for amelioration of an autoimmune disorders, such as expressing insulin an animal model for diabetes.

[00121] The chondrocytes were genetically altered as described in Example 2 to express the insulin gene, and placed into biological gel matrix substrates as described in Example 5. Slices of the solid gel, or a liquid gel that solidifies on contact, can be placed (e.g., into the pancreas) in an animal model of insulin (See e.g., Wong *et al. Supra*), and changes in the blood glucose levels can be observed.

Example 8: Use of Chondrocytes to Express a GABA in a Non-typical Chondrocyte Environment for Neurodegenerative Disorder

[00122] This example describes the use chondrocytes that have been genetically altered to express GABA an animal model for Parkinson's disease. The chondrocytes were genetically altered as described in Example 2 to express GABA, and placed into biological gel matrix substrates as described in Example 5. Slices of the solid gel, or a liquid gel that solidifies on contact, can be placed into a region of the brain (e.g., subthamic nucleus) in a model for Parkinson's disease (See e.g., Bjorklund *et al.*, *Supra*), and the amelioration of Parkinson's symptoms can be observed be monitoring the behavioral changes in the animal (e.g., by a maze test).

[00123] One skilled in the art will appreciate further features and advantages of the invention based on the above-described embodiments. Accordingly, the invention is not to be limited by what has been particularly shown and described, except as indicated by the appended claims. All publications and references cited herein are expressly incorporated herein by reference in their entirety.